Water Hammer Simulations of Monomethylhydrazine Propellant

Zachary Burkhardt, Jacobs ESSSA Group, University of Alabama in Huntsville
N. Ramachandran, Jacobs ESSSA Group, ER42, MSFC and A. Majumdar, ER42, MSFC

Introduction

Fluid Transient analysis is important for the design of spacecraft propulsion system to ensure structural stability of the system in the event of sudden closing or opening of the valve. Generalized Fluid System Simulation Program (GFSSP), a general purpose flow network code developed at NASA/MSFC is capable of simulating pressure surge due to sudden opening or closing of valve when thermodynamic properties of real fluid are available for the entire range of simulation. Specifically GFSSP needs an accurate representation of pressure-density relationship in order to predict pressure surge during a fluid transient. Unfortunately, the available thermodynamic property programs such as REFPROP, GASP or GASPAK do not provide the thermodynamic properties of Monomethylhydrazine (MMH). This work illustrates the process used for building a customized table of properties of state variables from available properties and speed of sound that is required by GFSSP for simulation. Good agreement was found between the simulations and measured data. This method can be adopted for modeling flow networks and systems with other fluids whose properties are not known in detail in order to obtain general technical insight.

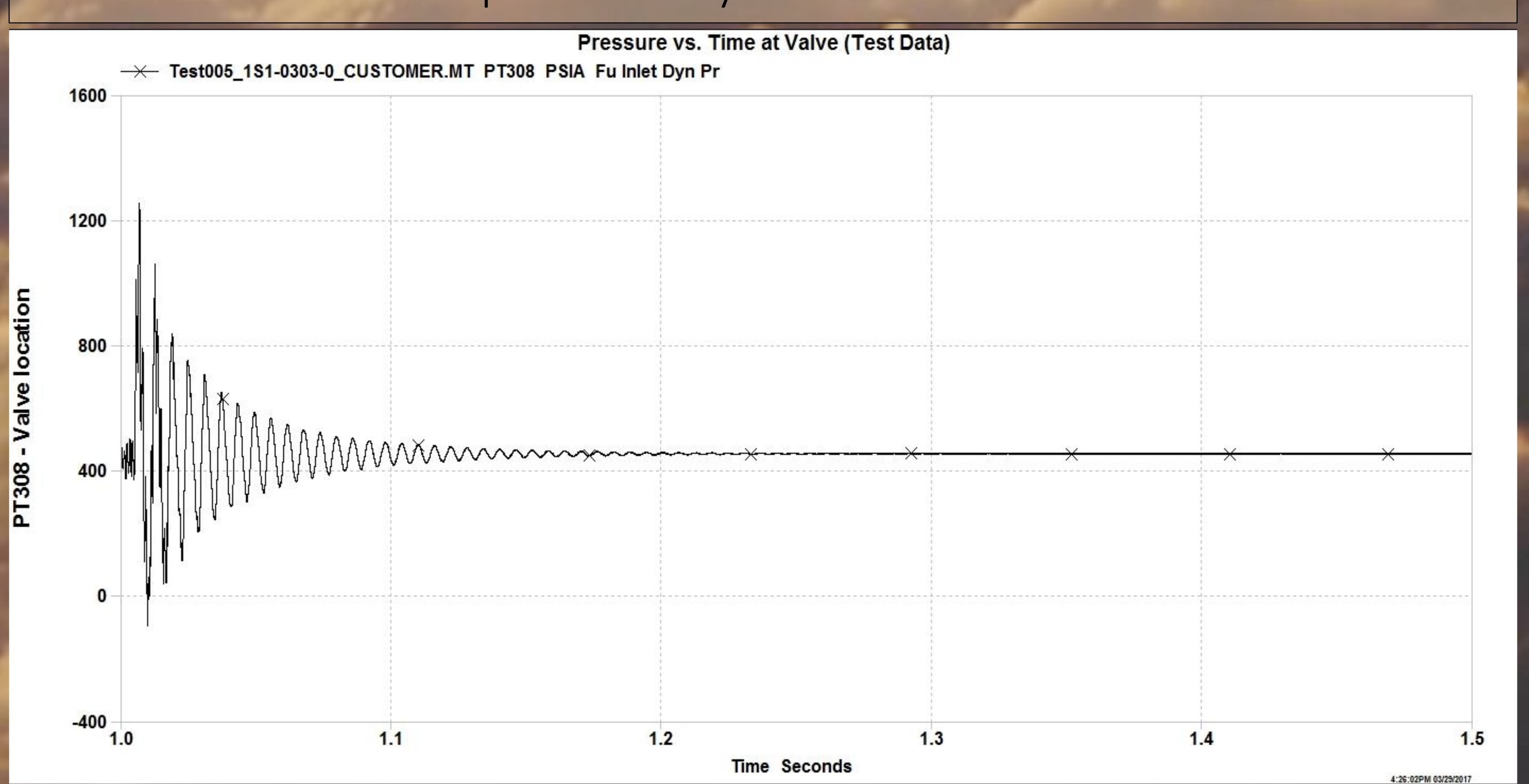
Background

- GFSSP uses a pressure based finite volume algorithm to model both steady-state and transient fluid system
- MOC (Method of Characteristics) uses speed of sound in the governing equation to model fluid transient
- Unlike MOC, GFSSP uses compressibility of fluid to model fluid transients.

Objective: Create GFSSP Compatible property tables for MMH and then use GFSSP to model fluid transients in a small MMH thruster that is under development.

Methodology

- GFFSP requires accurate pressure-density relationship for simulations. Since data for MMH is not readily available, this data was input using a customized routine implemented in Matlab.
- Analysis based on Airforce Propellants Handbook data for MMH. Equations of state were created using curve fits to the data.
- Created Matlab script to take the equations of state and create GFSSP compatible property tables.
- Code could be adapted for any other fluid.

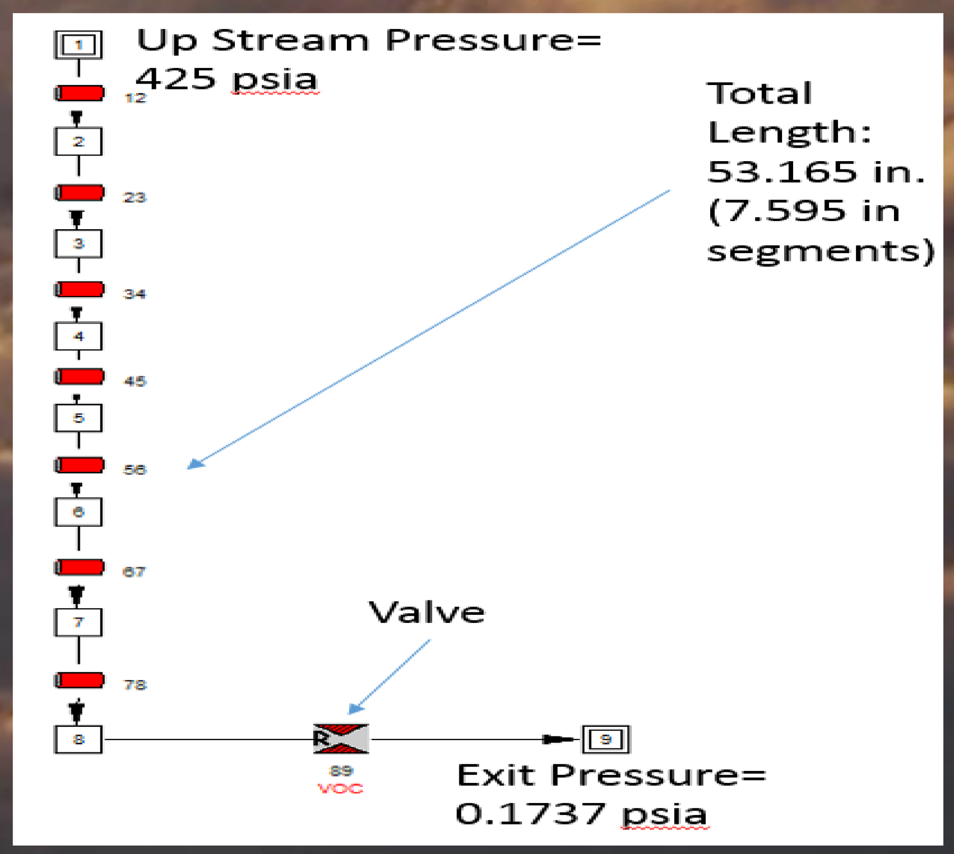


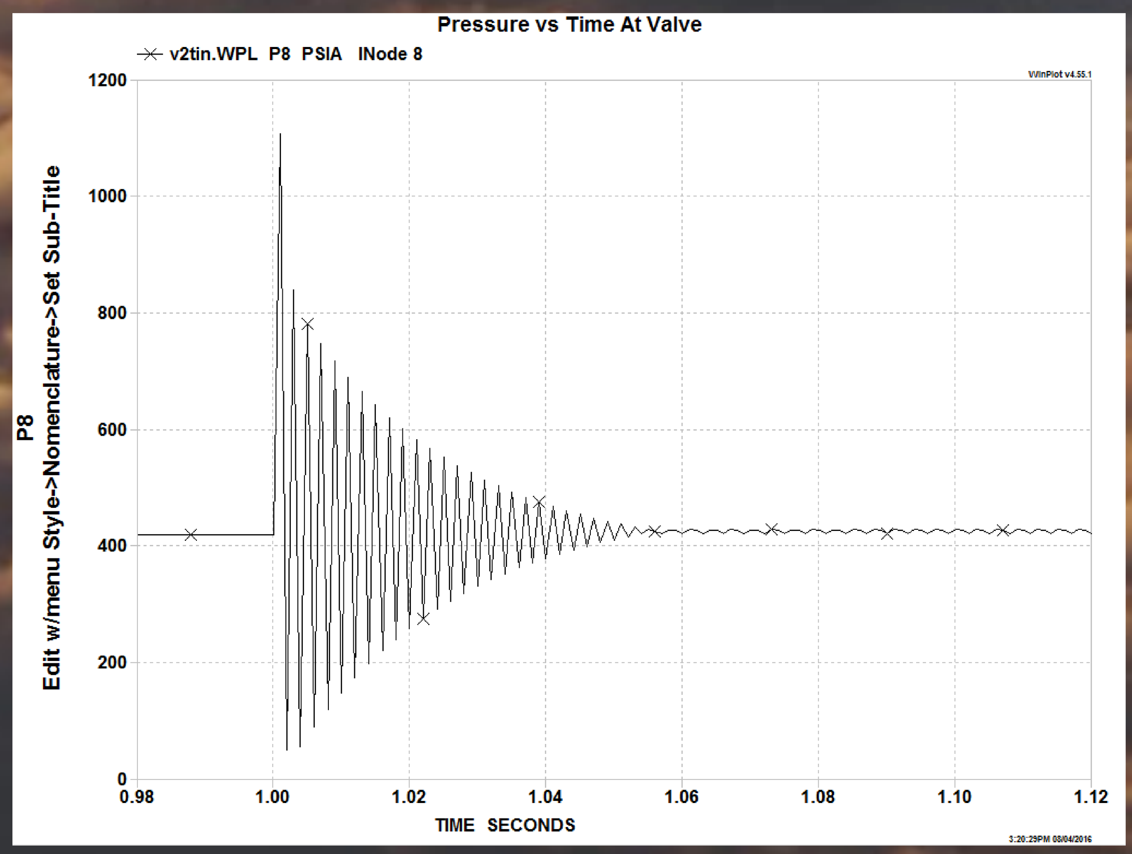
Algorithm

- Obtain data or equations for defining fluid properties as a function of pressure and temperature; density, dynamic viscosity, enthalpy, entropy, specific heat.
- For specialized liquids such as MMH, the required property data may not be available; e.g. density listed only as a function of T (incompressibility assumption). However, fluid transients such as water hammer occur due to fluid compressibility and this information is vital for GFFSP simulations.
- If the speed of sound in the fluid is known at a known temperature, then the pressure dependence on density can be estimated; e.g. a value of 5655 ft/s was used for the speed of sound in MMH [1].
- MMH property data for density, $\rho = \rho(p)$ was then generated for a fixed temperature, a valid assumption since the test was under isothermal conditions.
- Using equations [1] for $Cp = Cp(T)$, $\mu = \mu(T)$, and $h = h(T)$ property tables were then generated for specific heat, viscosity and enthalpy.
- GFFSP requires property values for ratio of specific heats, thermal conductivity and entropy even though they are not used in the transient calculations. This data could not be obtained from surveyed literature. Arbitrary values were generated as inputs to the code.

Preliminary Results

- A simplified flow network of the test configuration was developed as shown below.
- When proper boundary conditions were applied, the steady state simulation of the MMH test system in GFSSP was able to produce mass flow rates similar to those measured during the test.
- A transient simulation of the system with an nearly instantaneous (1 ms) valve closure was then executed:
  - With simplified model and proper GFFSP settings, the model runtime was very quick compared to other common analysis techniques.
  - Results demonstrated similar frequency response to that seen in data from an experimental test of the system (shown in plots below).
  - Water hammer oscillations decayed at approximately the same rate as the test data.
  - Amplitude of pressure oscillations was slightly different than expected. This can be attributed to the geometry simplification used in the simulation and due to the property (ρ) estimation with change in pressure.





(Left) Dynamic pressure data at the valve, from test , showing water hammer transients.
[Above Left] Simplified GFFSP model of test configuration showing boundary conditions.
[Above Right] Computed fluid transient at the valve due to near instantaneous valve closure, 1 ms.

Conclusions

- MMH property tables suitable for use in GFSSP were developed.
- MMH properties were used to analyze an MMH thruster system.
  - Steady state results closely matched expected values, indicating that the property tables are working in GFSSP.
  - Transient results show good agreement with experimental results with regard to the shape of the pressure history and the frequency response.
  - Oscillations decayed with time as expected.
  - Amplitude shows some error

Future Work

- GFSSP modeling of the damping effects of a helium bubble that can develop in the MMH Thruster system.
- Further verification of MMH simulations in GFSSP with experimental data.
- More detailed property tables and equations of state for MMH need to be developed to improve the accuracy of MMH transient analysis.
  - Lack of data over a range of pressures currently is a significant source of error.

Acknowledgments

Thanks to Dr. Matthew Casiano, ER42, MSFC for providing details about the project, test conditions and test datasets. Guidance from Dr. Andre LeClair, ER43, MSFC on implementing customized working-fluid property datasets into GFFSP is also appreciated. The work was done by the lead author during a summer internship in the Fluid Dynamics Branch under the guidance of Dr. Ramachandran.

References

1. US Air Force Propellants Handbook.
2. GFFSP User's Manual.